IEEE-1588 DEPLOYED ON THE EASTERN RANGE

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Abstract

The Air Force has installed a pilot program at the Eastern Range where new IEEE 1588 enabled GPS Timing receivers have been deployed at Cape Canaveral Air Force Station, Kennedy Space Center, and Patrick Air Force Base and are performance monitored, independently of GPS. This is the first known deployment of IEEE 1588 where Master and Slave IEEE 1588 devices have been installed on a single Ethernet network, over such a large area. The IEEE 1588 Grandmaster is located in the operations control center and is disciplined by a cesium steered by USNO via Two-Way Satellite Time Transfer System. An automated workstation at the operations control center collects health and status from the GPS receivers. GPS – IEEE 1588 difference data are also collected to validate that GPS timing signals provided to remote instrumentation are accurate within ± 2 microseconds. This paper will describe the recently deployed system and share some of the early performance data collected.

INTRODUCTION

The Eastern Range (ER) has used Synchronized Time Code Generators (STCGs) to provide timing signals to remote instrumentation sites. For many years, land line and RF distribution of Inter-Range Instrumentation Group (IRIG) standard time-of-year were the synchronizing signals of choice. In recent years, many ER remote Timing sites' STCGs have been replaced with modern GPS Timing Receivers capable of providing locally required time codes, repetition rates, and precision frequencies. All these methods required the use of portable clock to verify time accuracy of signals provided to remote instrumentation systems. Several efforts were made to implement a scheme to verify the timing accuracy of remote Timing sites' clocks from a central operations center. Until the introduction of the Institute of Electrical and Electronics Engineers (IEEE) 1588 Precise Time Protocol (PTP) standard, every scheme was too expensive or inaccurate to justify its implementation. This paper describes the IEEE 1588 implementation on the ER intended to provide real-time, time accuracy verification of remote timing sites.

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14. ABSTRACT
The Air Force has installed a pilot program at the Eastern Range where new IEEE 1588 enabled GPS Timing receivers have been deployed at Cape Canaveral Air Force Station, Kennedy Space Center, and Patrick Air Force Base and are performance monitored, independently of GPS. This is the first known deployment of IEEE 1588 where Master and Slave IEEE 1588 devices have been installed on a single Ethernet network, over such a large area. The IEEE 1588 Grandmaster is located in the operations control center and is disciplined by a cesium steered by USNO via Two-Way Satellite Time Transfer System. An automated workstation at the operations control center collects health and status from the GPS receivers. GPS â IEEE 1588 difference data are also collected to validate that GPS timing signals provided to remote instrumentation are accurate within Â± 2 microseconds. This paper will describe the recently deployed system and share some of the early performance data collected.

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THE SYSTEM

The Timing Health and Analysis Monitor System (THAMS) consists of the THAMS Server/Workstation and the Grandmaster IEEE 1588 clock located in the Morrell Operations Center (MOC), and Member/Slave IEEE 1588 clocks located at sites located at Cape Canaveral Air Force Station (CCAFS), Patrick Air Force Base (PAFB), and Kennedy Space Center (KSC). The THAMS Server/Workstation and Grandmaster/Member IEEE 1588 Clocks are connected via dedicated single fiber-optic strands, Ethernet switches, and media converters. The Grandmaster IEEE 1588 clock receives its initial synchronization from the Global Positioning System (GPS), and then maintains time by accepting 10 megahertz (MHz) from the Range Clock in the MOC, which is synchronized and syntonized to the Department of Defense Master Clock (DOD MC) at US Naval Observatory, via the Two-Way Satellite Time Transfer System. The primary function of the GPS Receivers at remote instrumentation sites is to provide specification compliant time to Range instrumentation. The THAMS enables operators to remotely verify the accuracy of time provided to Range users by comparing the times from GPS and IEEE 1588 at each Site Clock. Site Clock time accuracy measurement was expected to be in the microsecond range.

THE COMPONENTS

The significant component of the THAMS is the GPS Receiver assembly that is based on Symmetricom XLi IEEE 1588 Clock. This is a commercial-off-the-shelf item, which is installed with an antenna, in-line amplifier for cable lengths greater than 150 feet, antenna cable, two lightning arrestors, and the necessary hardware and adapters for installation and interface to the existing building structure and timing equipment. The GPS Receiver assembly has a Grandmaster IEEE 1588 plug-in module in Bay 4, a Member/Slave1588 plug-in module in Bay 2, a four-channel sine wave frequency output plug-in module in Bay 3, and a GPS Engine plug-in module in Bay 1.

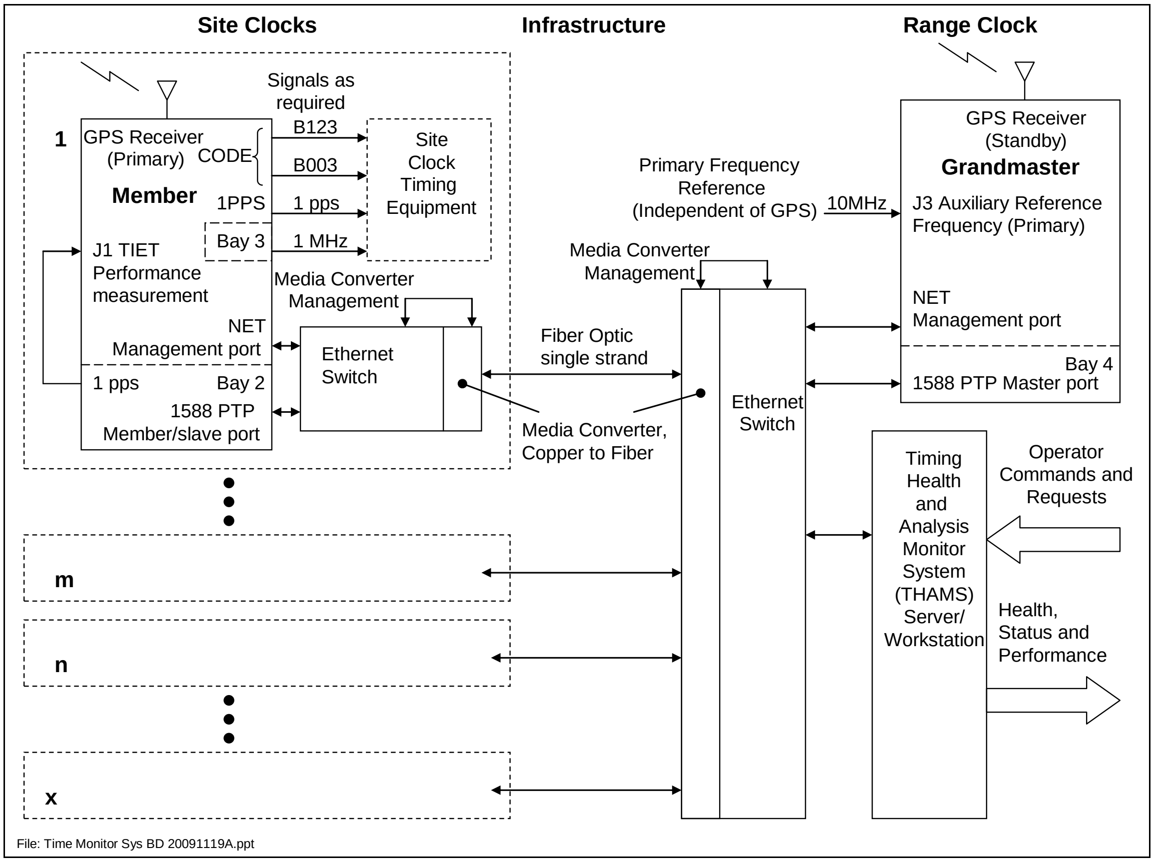

Figure 1. THAMS block diagram.

THE SOFTWARE

The THAMS Server/Workstation provides the operator a graphical user interface (GUI) to monitor, configure, and observe status of the GPS Receivers, Transition Networks, Inc., Media Converters, Cisco IE3000 Switches, and Dell PowerEdge 2950 III Server. The following software operating system and applications are installed on THAMS to provide for health, status, and control of the GPS Receivers and the Ethernet components:

THAMS Software

- Hewlett-Packard (HP) NNM 8i
- Symmetricom TimeMonitor XLi Software
- Symmetricom TimeMonitor Analyzer Software
- Rainbow Technologies Sentinel
- Transition Networks Focal Point 2.1 Management Software
- Hummingbird Connectivity Secure Shell Management Console

- Hummingbird HostExplorer Open Session
- Dell OpenManage Server Administrator.

The Symmetricom TimeMonitor XLi Software allows for monitoring the status of the GPS Receivers and capturing timing performance data. Once data collection is initiated, it will continue without manual intervention until an operator stops the collection, or data storage limit is reached (approximately 11 days of data is the longest collection period to date). However, if some event or failure disrupts collection and prevents the normal closing of the file, then all data since the start of collection are lost. The data collected may be saved to a file for additional analysis with the Symmetricom TimeMonitor Analyzer software application. The collected data may also be opened with Microsoft (MS) Excel 2007 as a delimited text file to a text file for further viewing and analysis. The Rainbow Technologies Sentinel application is loaded before the hardware universal serial bus (USB) key is installed. The hardware USB key is required to open the Symmetricom TimeMonitor applications.

THE SERVER/WORKSTATION

THAMS is implemented on a Dell PowerEdge Server Model 2950 III running MS Windows 2008 Server 64-Bit operating system. The computer has the following components:

THAMS Server Hardware Components

- Rackmount Chassis (2-rack units high, 19-inches wide)
- Dual Core XEON Processor: 2.0-gigahertz (GHz), 1333-megahertz (MHz) front-side bus, L2 cache
- System Memory: 8-gigabyte single-ranked Dual In-line Memory Modules
- Two 146- gigabyte Removable Hard Drives
- Optical Drive: Digital Versatile Disc – Rewriteable, Serial Advanced Technology Attachment, Internal
- Two Redundant, Server Power Supplies
- Two 10/100/1000 Network Interface Cards.

Communication Equipment☹

- Cisco IE3000 Ethernet Switch (SW)
- Transition Networks Media Converter.

LOCATION

Figure 3 shows a portion of Brevard County, Florida. THAMS equipment is located at Kennedy Space Center (KSC), Cape Canaveral Air Force Station (CCAFS), and Patrick Air Force Base (PAFB). The

figure shows the general location of the Morrell Operations Center (MOC) and the remote instrumentation sites. The system extends from the Radar 0.134 at Patrick Air Force base north 33 miles to the Playalinda Beach Distance Object Attitude Measurement System (DOAMS) north of the National Aeronautics and Space Administration (NASA) Shuttle launch pads. The east-west distance from the Range Communications Bldg to the Radar 19.14 is over 5 miles. The cable path from the Radar 0.134 to the MOC is approximately 15.9 miles. The cable distance from the MOC to the most distance site, the Playalinda Beach DOAMS, is approximately 21.3 miles.

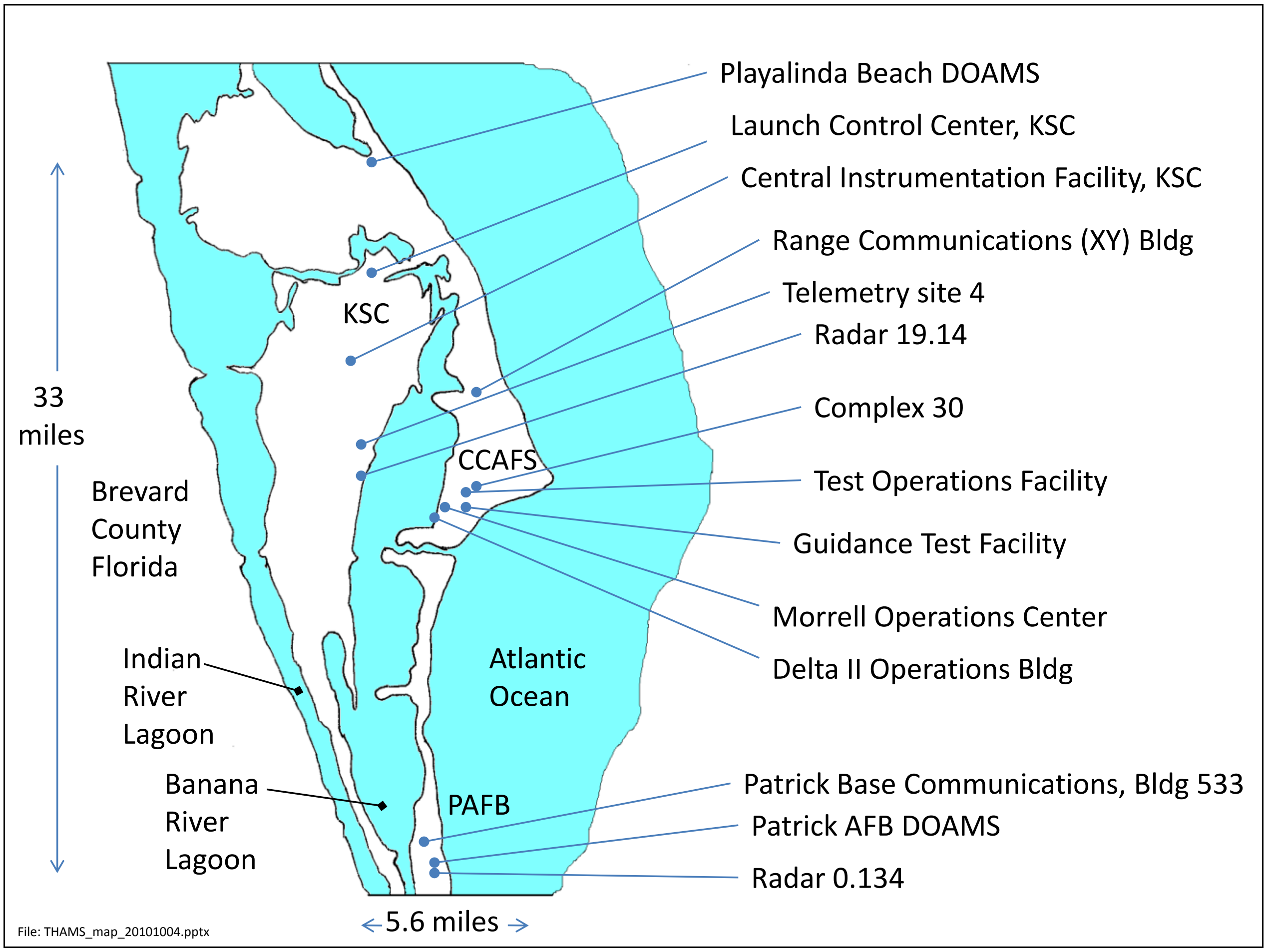

Figure 3. THAMS general location map.

THE ENVIRONMENT

The environment is depicted outside the circle in Figure 4. Two independent means of time transfer from USNO provides assurance that systemic problems are detected. The GPS receiver provides the timing signals needed at the remote instrumentation site. The operator submits requests current status and past performance data. The THAMS responds by saving requested performance data for later analysis and display of health and status data for immediate assessment.

The block diagram shown in Figure 5 provides network details. Single fibers are identified by the locally assigned reference designator. Full duplex media converter pairs convert the optical signals into the copper circuits at each Ethernet Switch (SW). Media converter and Ethernet Switch management ports have been omitted from this figure. All remote site GPS receivers are two, three, or four Ethernet Switches from the IEEE 1588 Grandmaster. The Ethernet Switches support either IEEE 1588 version 1 or version 2. However, since the GPS Receivers can support only IEEE 1588 version 1 at this time, the Ethernet Switches are configured for IEEE 1588 version 1 support.

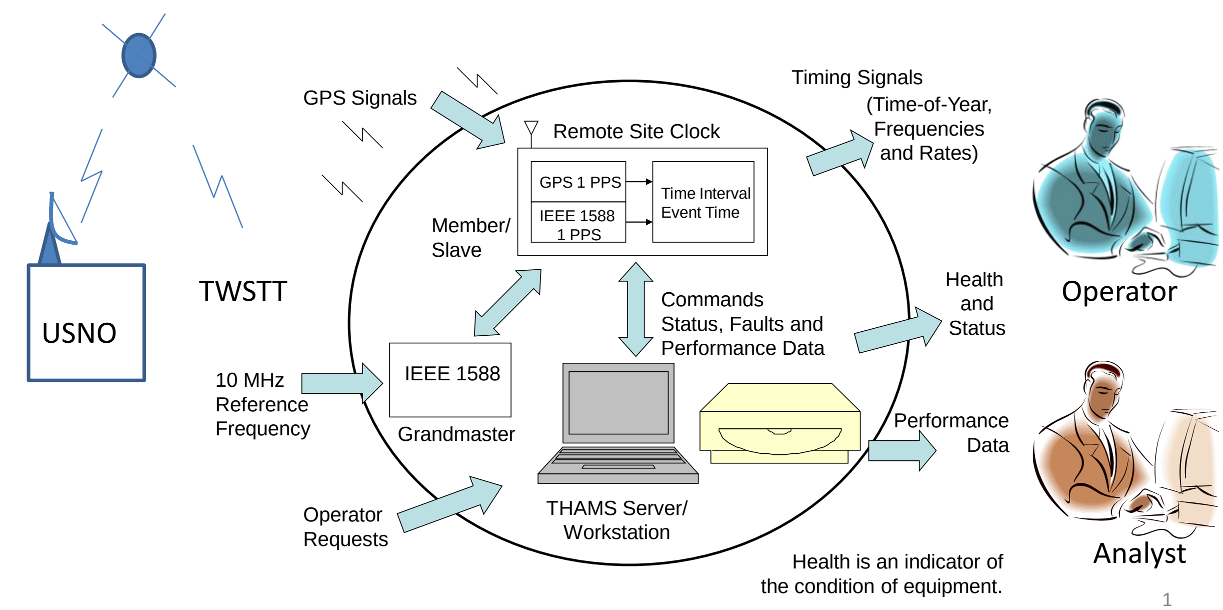

Figure 4. THAMS environment diagram.

SYSTEM ATTRIBUTES

The THAMS provides ER Timing Operators with a central monitoring capability where remote timing sites can be monitored for health, status, and time accuracy performance. The THAMS embedded Network Node Manager receives Simple Network Management Protocol real-time trap notification messages from Ethernet enabled devices, which are presented on the THAMS workstation/server monitor.

With a simple glance at the monitor, operators can determine the health and status of the network and the devices connected to it. Real time GPS – IEEE 1588 time difference data for each remote site are also available on the THAMS monitor. And there are Web interfaces to the Ethernet enabled devices that can be accessed to obtain detailed health and status and to effect configuration changes. This deployment of IEEE 1588 is successfully deployed over the largest known-to-date campus (approximate size of 175 square miles).

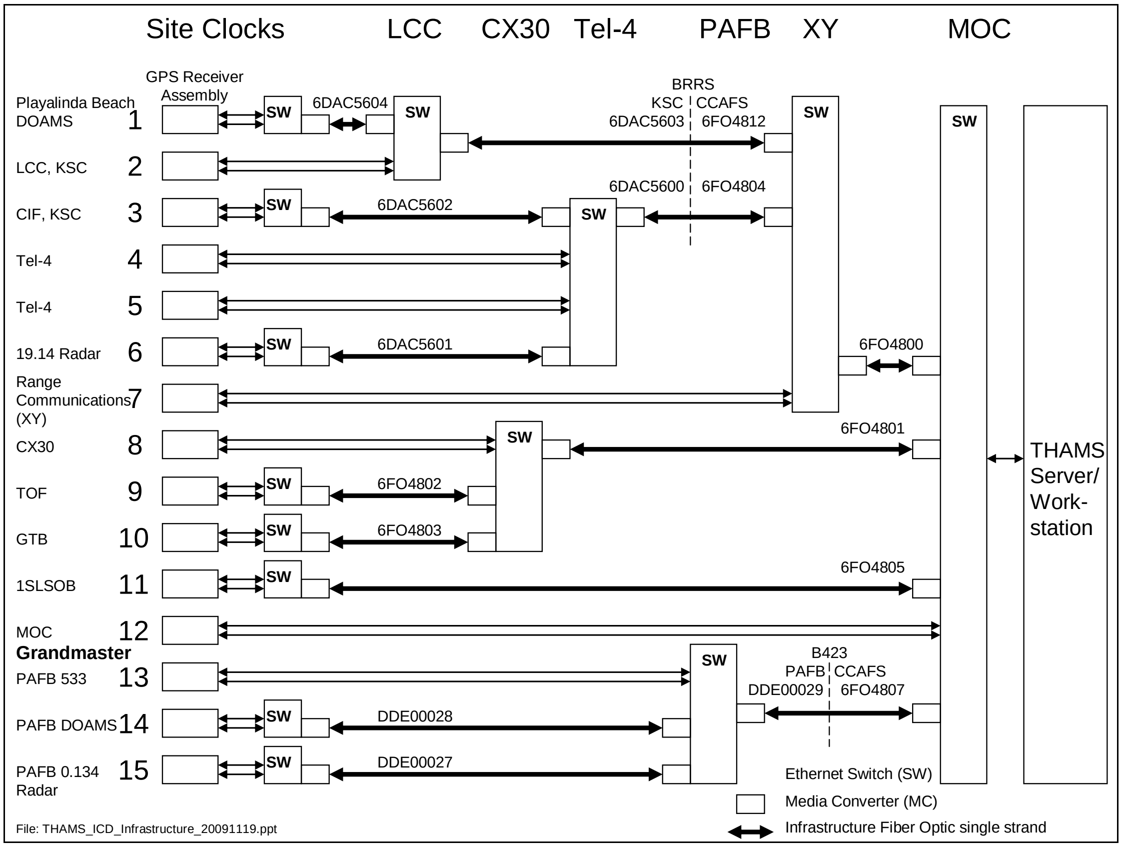

Figure 5. THAMS block diagram.

DATA COLLECTION

The data are collected in a .xli format compatible text format. See Figure 6 for a GPS – IEEE 1588 time difference data sample. As the figure shows, the time stamps are not monotonically increasing. This is the result of time-interval values either less than 1 second, or greater than 1 second. The first case results in two values captured in the same second. In the second case, no value is captured in the intervening second.

The Symmetricom TimeMonitor Xli software includes a utility TimeMonitor Analyzer for graphing and analysis of the data. This tool was used to graphically display the data in the following figures.

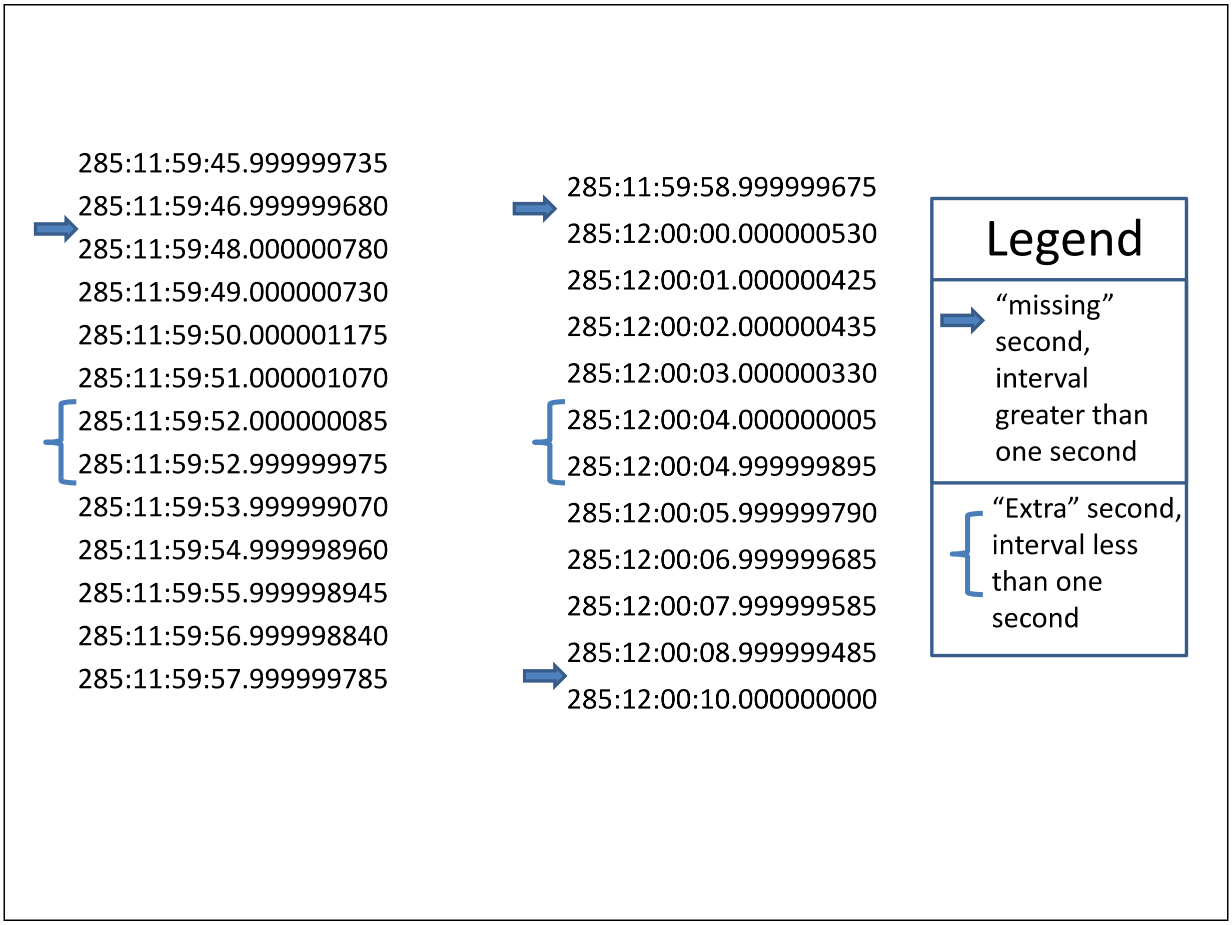

Figure 6. Data sample.

RESULTS AND DATA ANALYSIS

Figure 7 represents TimeMonitor Analyzer data collected from one of the remote timing sites for a period of 6 days. Evidently there are 15 time difference data excursions where the data indicates that the time difference between GPS and IEEE 1588 at the remote timing site approaches ± 6 milliseconds. Though rare, these time differences have been observed to approach 500 milliseconds. Expanding the X axis for the data set, such as Figure 8 for 1 hour/division, and Figure 9 for 10 minutes/division, additional time difference data excursions are observed. Not until "quiet" data are observed in presentation format for 1 minute/division (Figure 10) can data for each time difference measurement be observed without excursion. From these data, one must conclude that the goal of verifying time accuracy performance with less than 2-microsecond precision cannot be achieved in real time.

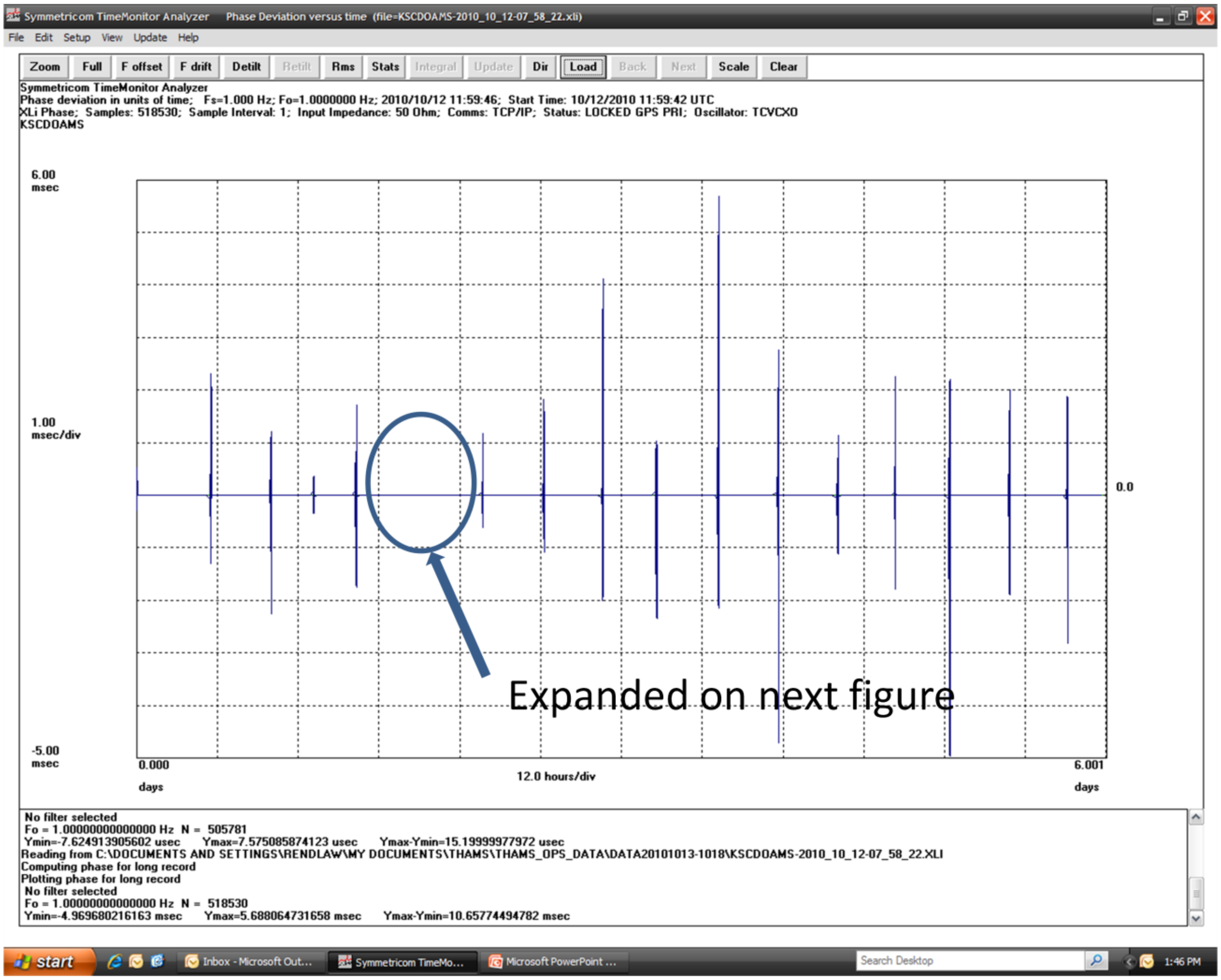

Figure 7. Remote site data (6 days, 12 hours per division).

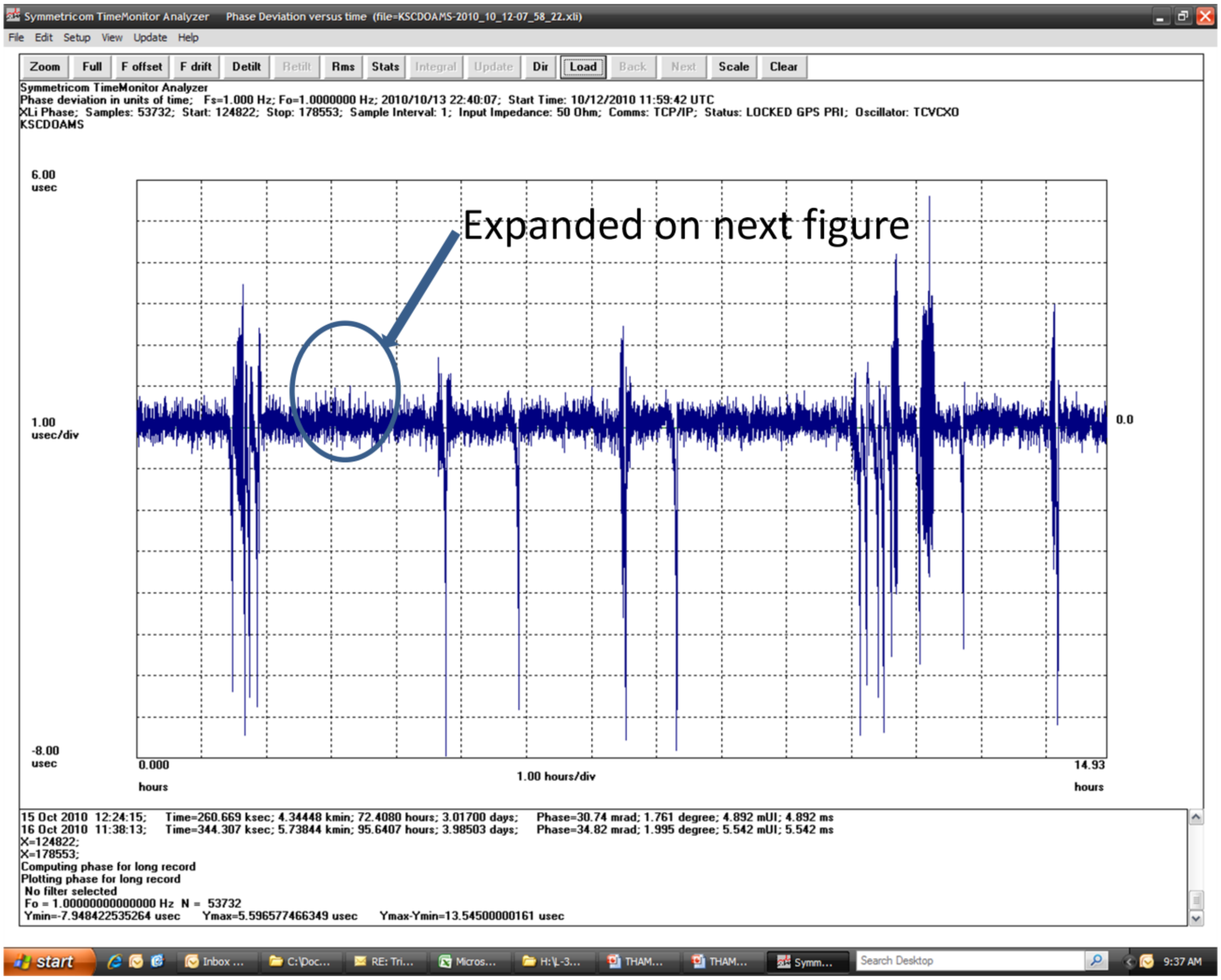

Figure 8. Remote site data (15 hours, 1 hour per division).

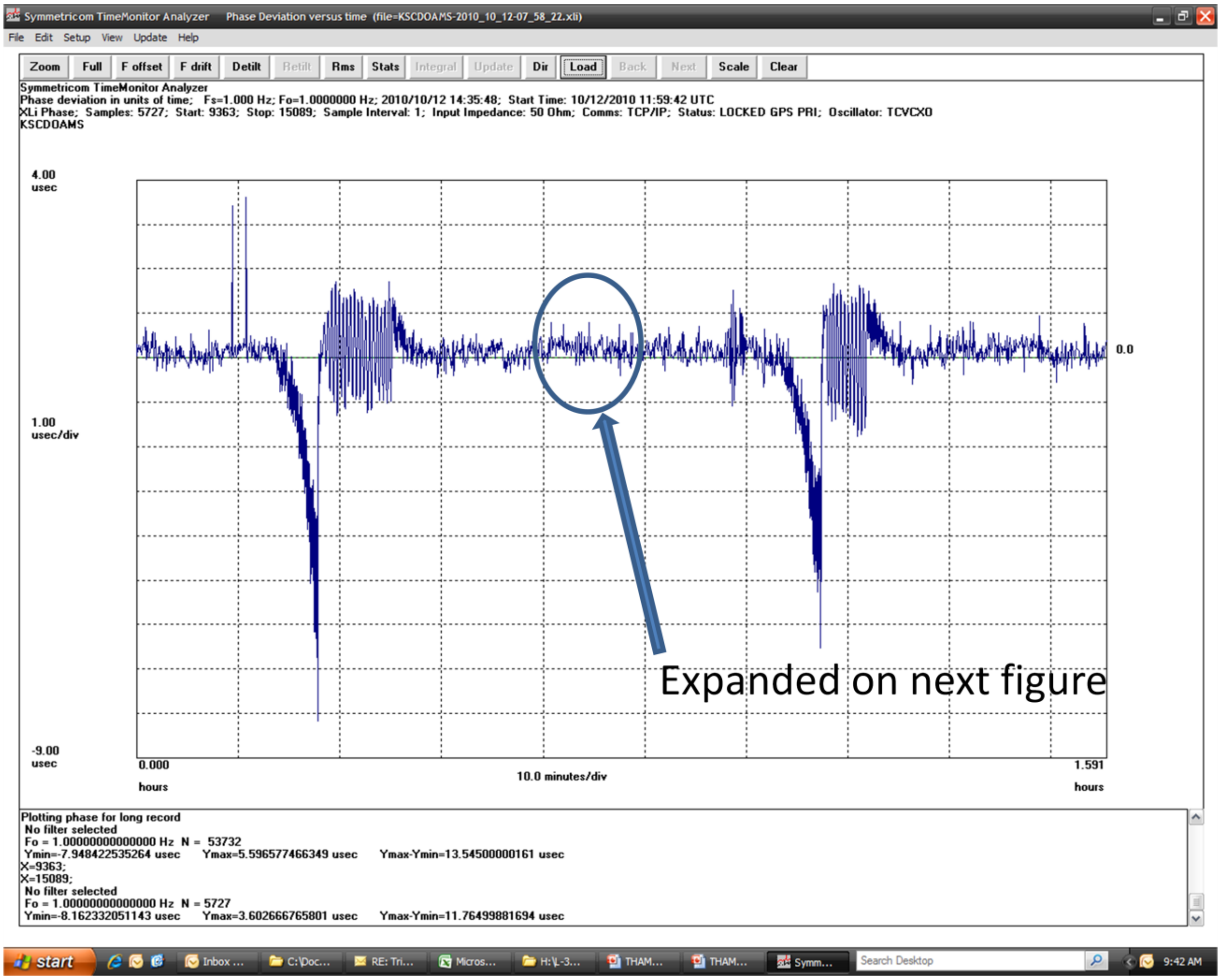

Figure 9. Remote site data (1.6 hours, 10 minutes per division).

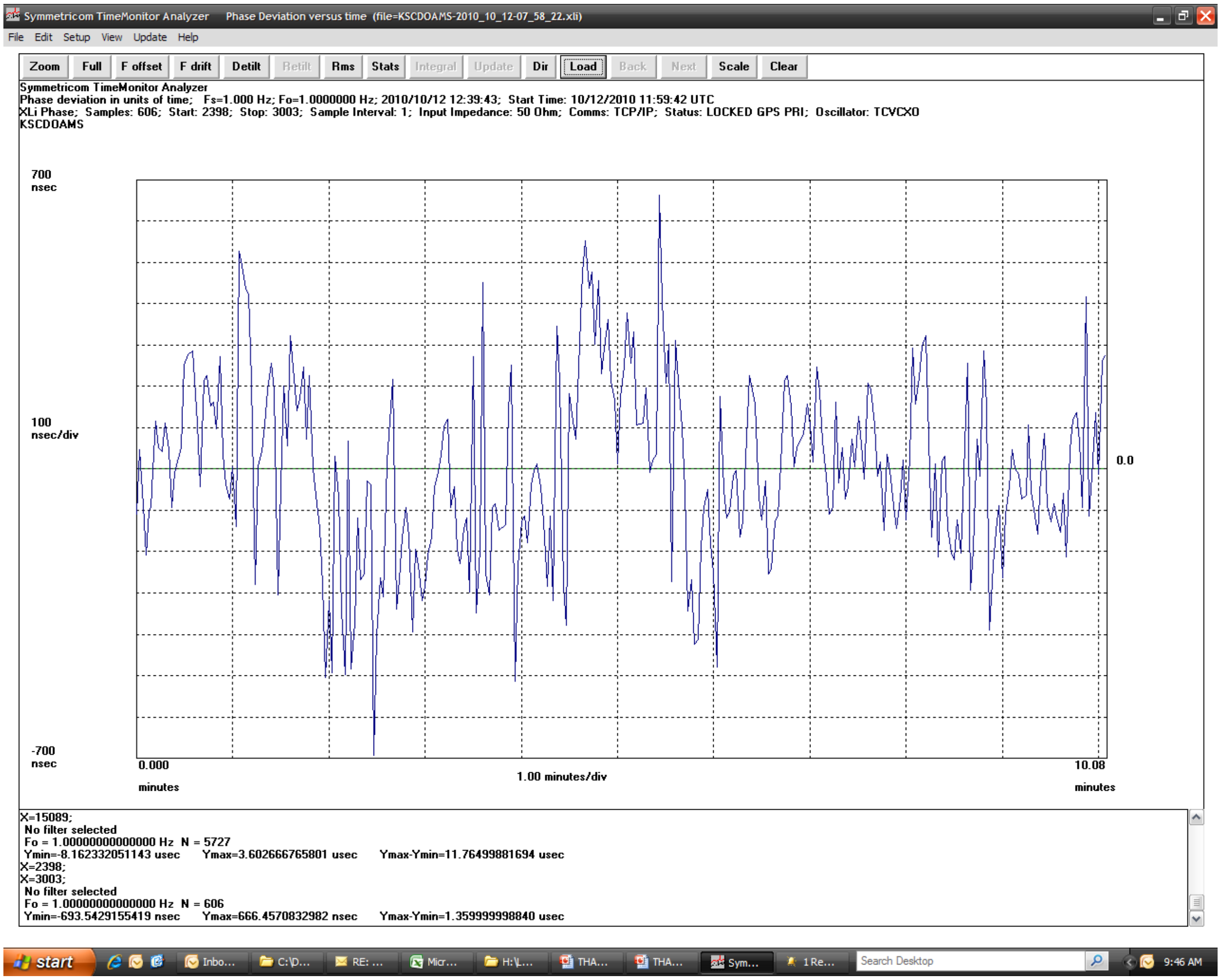

Figure 10. Remote site data (10 minutes, 1 minute per division).

Postprocessing of the time difference data was performed using the technique of removing outlier time difference data that exceeds 3 times the standard deviation from the mean value. This technique has to be applied for most data sets 2 to 4 times, effectively eliminating 1 to 3 percent of data collected, to determine a nominal time difference data set for the remote timing sites. With the above postprocessing, remote timing site time accuracy performance, with a precision of less than 2 microseconds, can be achieved in most cases. However, time difference data excursions of ± 8 microseconds still are evident. Reference Figure 11.

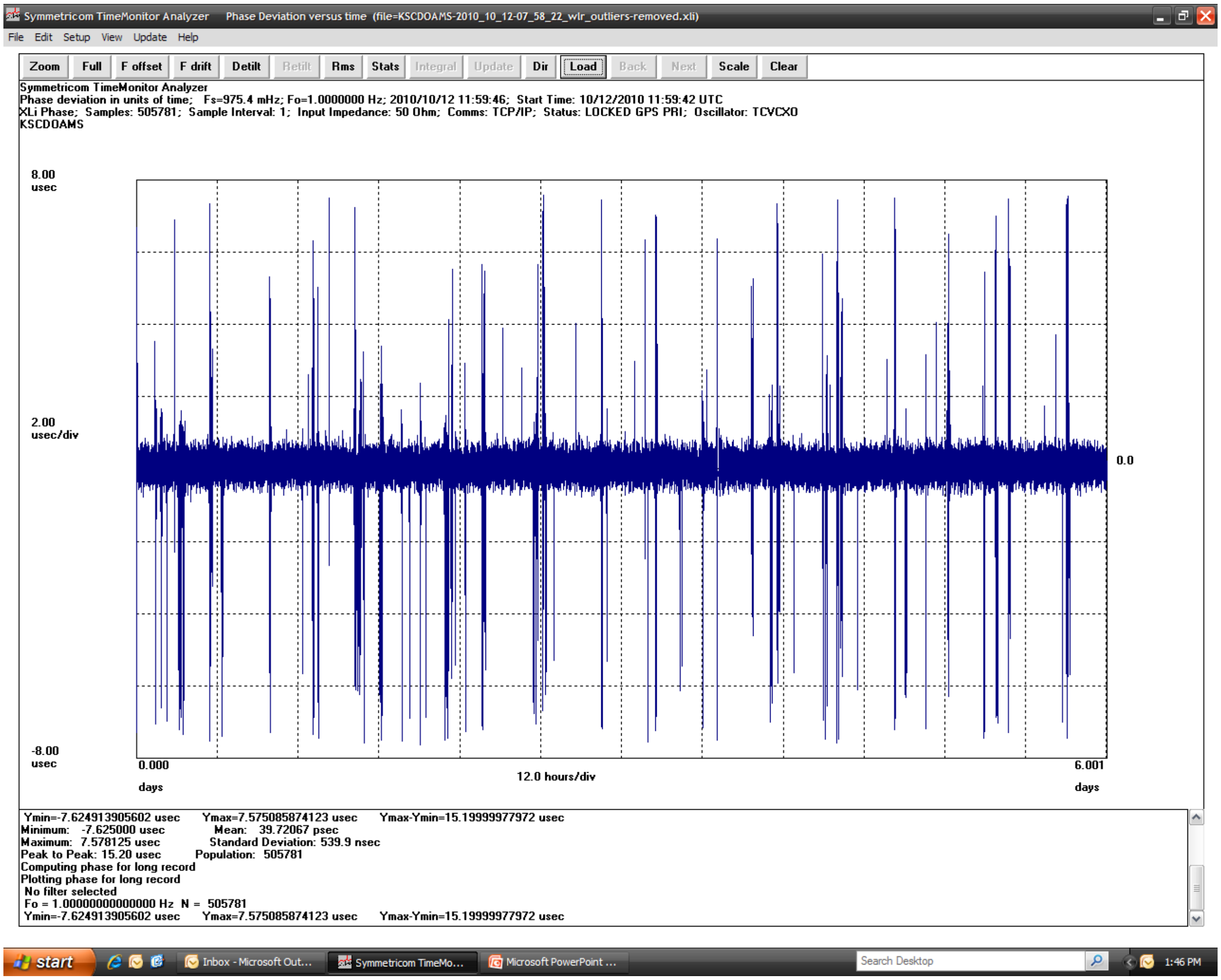

Figure 11. Plot with outliers removed (6 days, 12 hours per division).

POTENTIAL IMPROVEMENTS

The Symmetricom XLi GPS Receiver lacks secure protocols, which pose significant Information Assurance issues for Air Force installations. Symmetricom reports that they will ultimately provide secure protocol upgrades for the XLi GPS Receiver. However, at this time the release date for this upgrade is unknown.

The source(s) of the GPS – IEEE 1588 time difference data excursions are unknown. Potentially upgrading the GPS Receivers and THAMS network to use IEEE 1588 version 2 will alleviate these data anomalies. Symmetricom reports that IEEE 1588 version 2 for the XLi GPS Receivers is planned. However at this time, the release date for this upgrade is unknown. Other potential upgrades should be considered if there is sufficient potential that the time data excursions can be mitigated.

SUMMARY AND CONCLUSION

The ER has deployed IEEE 1588 over the largest campus known by the authors of this paper. Unlike many IEEE 1588 applications where IEEE 1588 is used to distribute precise time over a network, the main application for this network is to provide a real-time means for monitoring the time accuracy performance of remote timing systems. These remote timing sites use IEEE 1588-enabled GPS Receivers to provide timing signals to ER instrumentation across Cape Canaveral Air Station, Patrick Air Force Base, and Kennedy Space Center. The THAMS network provides improved health, status, and time accuracy performance monitoring. In that, real-time monitoring of remote timing sites has been achieved. However, this system has not achieved the goal of monitoring, in real time, time accuracy performance of remote timing sites with a precision of better than 2 microseconds. The GPS – IEEE 1588 time difference data excursions are problematic and their causes are unknown by the authors. Further investigation is warranted.

Acronyms List

1SLSOB	1st Space Launch Squadron Operations Building (Squadron was disbanded and facility is now called the Delta II Operations Building)
CCAFS	Cape Canaveral Air Force Station
CIF	Central Instrumentation Facility
DOAMS	Distant Object Attitude Measurement System
DOD MC	Department of Defense Master Clock
ER	Eastern Range
Gb/s	Gigabits per second
GPS	Global Positioning System
GTB	Guidance Test Building
HP	Hewlett-Packard
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet protocol
IRIG	Inter-Range Instrumentation Group

KSC	Kennedy Space Center
LCC	Launch Control Center
Mb/s	megabits per second
MHz	megahertz
MC	Media Converter
MOC	Morrell Operations Center
MS	Microsoft
PAFB	Patrick Air Force Base
pps	pulse per second
PTP	Precise Time Protocol
RF	radio frequency
SLRSC	Spacelift Range System Contract
STCG	Time Code Generators
SW	Switch assembly
Tel-4	Central Telemetry Station
THAMS	Timing Health and Analysis Monitor System
TOF	Test Operations Facility
XY	Range Communications (building)